

[Document Name]

Specification

[Title of the Invention]

Gold Alloy Bonding Wire

[Technical Field]

[0001]

The present invention relates to a gold (Au) alloy bonding wire for wire bonding of semiconductor devices used in connecting an electrode (pad) at a semiconductor integrated circuit device with an electrode (external lead) connected to a printed circuit board, and in particular it relates to a gold (Au) alloy bonding wire which is drawn to a diameter of 20 μm or thinner and designed to minimize the surface segregation of minor trace elements contained in it.

[Background Technology]

[0002]

Conventionally, an Au alloy bonding wire having a purity of 99.99 mass % or higher is frequently used to make lengths of wires having a diameter of 25 to 35 μm for connecting a pad on a semiconductor chip to an external lead, in a semiconductor manufacturing equipment.

Normally, for connecting or stitching an Au alloy bonding wire the ultrasonic-and-thermoccompression hybrid bonding method is adopted in the case of the first bonding.

In this method, the fore end of a wire exposed from the fore end of a capillary tube is thermally melted by micro electro discharging, and the wire end then shapes into a ball (more precisely a bulb) by virtue of its surface tension, and then this ball part is bonded by compression on an electrode of a semiconductor

device heated to a temperature range of 150 - 300 °C (ball bonding), and the later second bonding is conducted by directly bonding the bonding wire to the external lead by means of ultrasonic compression (wedge bonding).

[0003]

In order to be used for a semiconductor device like a transistor, an IC, etc., the items including the semiconductor chip, the bonding wire, and that part of the lead frame where the semiconductor chip is attached are sealed with an epoxy resin for the purpose of protection, after they have received the bonding operation with the bonding wires.

Recently, the ever increasing demand for smaller, thinner, higher-functional, and higher-dependable semiconductor devices has caused the properties needed for Au bonding wires to diversify, and in order to cope with the situation wherein the semiconductor chips have greater numbers of pins and thus smaller pin-to-pin pitches, it is required that the diameter of the Au bonding wire should be correspondingly minimized, and at the same time, it is required of the Au bonding wires to have greater strength, the ability to produce a ball of improved sphericity for compression bonding, improved bonding ability at the second bonding, and furthermore a longer bond (junction) durability.

[0004]

In particular, the tendency for making the semiconductor devices smaller, thinner and higher performing, the sizes of the semiconductor equipments are becoming smaller. Accompanying this tendency, the numbers of output and input terminals per unit area are increasing and correspondingly the pad pitches (the intervals between the pad centers) have been decreasing from 100 μm to 80 μm and even to as small as 60 μm . In the consequence, the diameters of the bonding wires are also beginning to decrease from 25 μm to 20 μm or even smaller, and trials have been made by some person to make wires having a diameter of 15 μm and even smaller.

However, as the diameter of the bonding wire gets smaller, the absolute rigidity of the wire itself is lowered and the diameter of the melted ball at the wire end is reduced, so that problems have arisen that had not been experienced in the case of a 25- μm thick wires or so, such as leaning, deficiency in the bonding

(junction) strength of the ball for compression bonding, and insufficiency in the time length of bond durability. Now, the meaning of "leaning" is defined as a phenomenon wherein the wire spanning between the first bonding and the second bonding fails to keep standing but falls to the right or to the left, and as a result of this, the distance from the neighboring wire becomes too short or even the wires contact with each other with negative consequences.

[0005]

Thus, for example, as disclosed in the Publication-in-IP 1, in order to cope with the narrow pitch of 50 μm for high density wiring designs, a bonding wire having a diameter of 20 μm is proposed for improvement of junction reliability of the bonding wire sealed with an environment-conscious encapsulating resin containing a phosphorus compound and/or a hydroxide, said bonding wire being made of an Au alloy consisting of at least one element selected from Cu, Pd, Pt, Zn and Ag (first group elements) in an overall concentration (C1) falling in the range of 0.005 to 1.5 mass %, and of at least one element selected from Ca, Ce, Eu, Dy and Y (second group elements) in an overall concentration (C2) falling in the range of 0.001 to 0.06 mass %, and of at least one element selected from La, Mg, Gd, Tb and Ni (third group elements) in an overall concentration (C3) falling in the range of 0.001 to 0.05 mass %, and of the remnant which is gold and unavoidable impurities (section [0026] of Publication-in-IP 1).

[0006]

Now, if a wire is made of an Au alloy doped with some minor trace element(s), its absolute rigidity is heightened compared with a non-doped Au alloy wire, and the greater the amount of the minor trace element doping, the higher does the wire's absolute rigidity become, whereby various properties are improved, while some unwelcome properties may show up.

In a case in which a minor trace element that tends to improve the capability of an Au alloy matrix to form loop is added to an Au alloy matrix, the capability of the resulting Au alloy to form ball can be weakened, and its capability to bond to wedge may also be weakened. Furthermore, some elements added to the Au alloy can segregate in the surfaces of the melted ball and the wire and be oxidized, and a pit may occur in the fore end of the ball bulb, which pit is called

"hikesu" in Japan. When an added element is segregated in the surface of the wire and is oxidized, such an oxide causes deficient connection between the metals, as in ball bonding to the pads of semiconductor devices (connection between gold [Au] and aluminum [Al]) and as in wedge bonding to the external lead (connection between gold [Au] and silver [Ag]). Also, if the melted ball has a hikesu (pit), and the ball as such is bonded to a pad of a semiconductor device, there occurs an area in the middle of the contact interface where there is no meta-to-metal contact, which is called "nakanuke" in Japan, and as a result the overall bond (junction) strength is lowered.

Also, doping of an amount of a minor trace element may cause the ball for bonding to have a distorted shape, so that it becomes difficult to carry out ball bonding at a narrowed pin-to-pin pitch, and such doping may also harden the ball so much that a chip could crack, and the occurrence rate of pad damage (unwelcome phenomena such as detachment of the pad from the substructure, and Al splash, which is a reduction of the film thickness caused as Al is pushed off from the pad) could increase; therefore it is not allowed to add too much of minor trace element(s).

For example, in a case wherein the wire strength is secured by means of an addition of calcium (Ca) alone, this element can segregate partially in the surface of the ultra thin wire, and this (Ca) is oxidized to form an oxide film surface, whereby the ball shape at the first bonding and the ball's bonding (junction) capacity are rendered unstable, with the result that the roundness of the compressed ball is impaired and the wedge bonding strength of the second bond is weakened.

[0007]

Also, in a case wherein the number of the added elements are many, these elements in the Au alloy function in such a complex manner that segregation takes place in the surface of the melted ball, so that it is not possible to obtain a good initial bonding, and hence the tendency of failing to obtain a dependable junction of the first and second bonds becomes strong. Thus, as described in Publication-in-IP 2, a bonding wire has been developed of which the number and amounts of the added elements are controlled in such a manner that even if the ball bonding is conducted in the atmosphere no oxide film is formed in the surfaces of the melted ball and the ultra thin wire and thus the bonding capacity

is improved, and the economy is also improved in that the tendency of formation of inter-metal compounds becomes lower.

Prior Publications

Publications-in-IP

[0008]

Publication-in-IP 1: Japanese Patent Application Publication 2003-133362

Publication-in-IP 2: WO2006-35803

Summary of the Invention

Problems the invention seeks to solve

[0009]

However, in the case of a wire as thin as 20 μm in diameter, it is necessary to increase the mechanical strength of the wire by 30 % or more in order to secure the mechanical strength equal to that of a thin wire having a diameter of 23 μm ; but, in general, when the mechanical strength is increased the flexibility of the wire is reduced. Hence, even in a case wherein there occurred no oxide film in the surfaces of the melted ball and the ultra thin wire in the atmosphere, and wherein a loop of the wire having a high mechanical strength is made to span from the first bond to the second bond, the base of the compressed ball of the first bond becomes liable to crack, and thus the problems of so-called neck damage and neck disruption were caused.

This problem has not been solved in spite of the improved junction reliability and improved ball sphericity which are gained by the bonding wire by being made of an Au alloy containing palladium (Pd), etc., to which predetermined amounts of a second element(s) such as Ca and a third element(s) such as La are added, as described in sections [0033] and [0034] of Publication-in-IP 1.

Now, calcium (Ca) and beryllium (Be) and rare earth elements are known to segregate to lesser extents than zinc (Zn) and other elements in the surface of the melt ball, in which they are doped in small amounts.

However, when the ball bonding is repeated continuously for hundreds of thousands of times in the atmosphere, element(s) segregates and its oxidation takes place in the surface of and the fore front part of the capillary, so that the shapes of compressed balls at the first bond and the second bond turn improper, which gives rise to insufficient junction strength and even failure of junction; also, as the surface and the fore front part of the capillary become less lubricant (less slippery), the base of the compressed ball receives an active force while the loop is formed after the first bonding, and is liable to crack. Furthermore, when the lubricity of the capillary is weakened, problems in loop forming such as abnormal loop height and improper wire curving into a shape of letter S take place, besides leaning, and as a result, the wire could be caused to flow during the sealing with an epoxy resin. This phenomenon would, more than ever before, cause problems of over-narrowing and mis-contact between neighboring wires, with the recent progress of miniaturization and high density wiring design trend of the semiconductor devices. Also, with the improved performance of the bonding machines, the bonding speed (number of bonding done per unit time) is heightened, and with this higher bonding speed the lubricity of the capillary surface is diminished (that is, the frictional resistance is increased) more increasingly, and when the bonding speed is increased, the effects due to the loss of the lubricity (i.e., increase in the frictional resistance) of the surface and the fore front part of the capillary become more consequential.

[0010]

It is an object of the present invention to provide a bonding wire which, even when made to have a diameter of only 20 μm or smaller, does not experience segregation of minor trace element(s), but has them uniformly doped in the gold (Au) alloy matrix consisting of Au and palladium (Pd), etc., and which maintains the surface and the fore front part of the capillary sufficiently slippery so that the frictional resistances of them are not allowed to increase, whereby the neck damage and other problems that may occur at the time of loop formation are prevented.

This object and others are applicable even to a case wherein the total amount of the doped minor trace elements is 100 ppm or less.

Means to solve the Problems

[0011]

The present inventors went through extensive studies to solve these problems and came to complete the present invention.

In particular, according to the present invention, a gold (Au) alloy bonding wire as described below is proposed.

(1) A gold (Au) alloy bonding wire drawn to a diameter of 20 μm or less, which is composed of an Au alloy matrix and minor trace elements, said Au alloy matrix being prepared by adding at least one out of palladium (Pd), platinum (Pt) and copper (Cu), which have a purity of no less than 99.9 mass %, in a total amount of 0.05 to 2 mass % to gold of a purity of no less than 99.999 mass %, characterized in that said minor trace elements consist of calcium (Ca) in an amount of 5 - 50 mass ppm, magnesium (Mg) in an amount of 5 - 50 mass ppm, and lanthanum (La) in an amount of 5 - 50 mass ppm.

[0012]

(2) A gold (Au) alloy bonding wire drawn to a diameter of 20 μm or less, which is composed of an Au alloy matrix and minor trace elements, said Au alloy matrix being prepared by adding at least one out of palladium (Pd), platinum (Pt) and copper (Cu), which have a purity of no less than 99.9 mass %, in a total amount of 0.05 to 2 mass % to gold of a purity of no less than 99.999 mass %, characterized in that said minor trace elements consist of calcium (Ca) in an amount of 5 - 50 mass ppm, magnesium (Mg) in an amount of 5 - 50 mass ppm, lanthanum (La) in an amount of 5 - 50 mass ppm, and beryllium (Be) in an amount of 1 - 20 mass ppm.

[0013]

(3) A gold (Au) alloy bonding wire drawn to a diameter of 20 μm or less, which is composed of an Au alloy matrix and minor trace elements, said Au alloy matrix being prepared by adding at least one out of palladium (Pd), platinum (Pt) and copper (Cu), which have a purity of no less than 99.9 mass %, in a total amount of 0.05 to 2 mass % to gold of a purity of no less than 99.999 mass %, characterized in that said minor trace elements consist of calcium (Ca) in an

amount of 5 - 50 mass ppm, magnesium (Mg) in an amount of 5 - 50 mass ppm, lanthanum (La) in an amount of 5 - 50 mass ppm, and at least one of cerium (Ce), yttrium (Y) and europium (Eu) in a total amount of 1 -30 mass ppm.

[0014]

(4) A gold (Au) alloy bonding wire drawn to a diameter of 20 μm or less, which is composed of an Au alloy matrix and minor trace elements, said Au alloy matrix being prepared by adding at least one out of palladium (Pd), platinum (Pt) and copper (Cu), which have a purity of no less than 99.9 mass %, in a total amount of 0.05 to 2 mass % to gold of a purity of no less than 99.999 mass %, characterized in that said minor trace elements consist of calcium (Ca) in an amount of 5 - 50 mass ppm, magnesium (Mg) in an amount of 5 - 50 mass ppm, lanthanum (La) in an amount of 5 - 50 mass ppm, and beryllium (Be) in an amount of 1 - 20 mass ppm, and at least one of cerium (Ce), yttrium (Y) and europium (Eu) in a total amount of 1 -30 mass ppm.

[0015]

(5) Any of the gold (Au) alloy bonding wires as described in the preceding paragraphs (1) through (4), wherein the total amount of the minor trace elements is 100 mass ppm or smaller.

Effects of the Invention

[0016]

As an effect of the elemental composition of the gold (Au) alloy of the present invention, the bonding wire made of it does not suffer a neck damage of the compressed ball, which otherwise may be caused by degradation of the quality of the capillary surface.

Also, as the gold (Au) alloy of the present invention is so composed that it effectively heightens the mechanical strength of the wire made of it, the wire of the present invention is able to prevent both leaning and wire flowing as effectively as a wire having a diameter exceeding 23 μm does.

Incidentally, the gold (Au) alloy of the present invention is so composed that the

wire made of it is able to produce a melt ball and a compressed ball as round as conventional gold wires do.

Also, in the present invention the contents of the minor trace elements and impurities are minimized as much as possible, so that the degradation of the quality of the surface of the capillary is restricted and as a result, the roundness of the compressed ball is not impaired in the first bond and the second bond, and thus there occurs few failure of junction, and it is possible to repeat the bonding for hundreds of thousands of times continuously in the atmosphere more dependably than before.

How to practice the Invention

[0017]

The gold (Au) alloy bonding wire according to the present invention gains desired characteristics through addition of selected minor trace elements in respectively selected amounts to a matrix alloy prepared by adding to (i) gold of a purity of no lower than 99.999 mass % (ii) at least one out of palladium (Pd), platinum (Pt) and copper (Cu), which have a purity of no lower than 99.9 mass %, in a total amount of 0.05 to 2 mass %.

[0018]

Elements such as palladium (Pd), platinum (Pt) and copper (Cu) are each capable of forming a complete solid solution with gold (Au), but when each one is lean in amount in forming such a binary alloy, such lean element is apt to segregate from gold (Au). Hence, inasmuch as the total content prescribed for these elements is 2 mass %, the purities of them are selected to be no lower than 99.9 mass %. The higher the purities of them are, the greater the result, and in order to avoid ill-effects of impurities 99.99 mass % is preferable for their purities. Especially it is preferable that copper (Cu) has a purity of 99.999 mass % or higher. Of these elements palladium (Pd) and platinum (Pt) are more preferable than copper (Cu), in that they are hardly oxidized in the atmosphere and hence do not contaminate the capillary even when they evaporate during the formation of the melt ball.

Although palladium (Pd) is more liable to be oxidized than platinum (Pt), it is

more capable than platinum (Pt) of restricting the accumulation of segregated substance and oxide on ceramics, of which the capillary is usually made of, and thus palladium (Pd) is the most preferred. When two or more of palladium (Pd), platinum (Pt) and copper (Cu) are co-doped into the matrix alloy, there is not limit to the ratio between the two dopants. This is by virtue of the fact that palladium (Pd) and platinum (Pt) show equal matrix effects toward gold (Au).

[0019]

In the present invention, if the addition of at least one out of palladium (Pd), platinum (Pt) and copper (Cu) is in a total amount of less than 0.05 mass %, the resulting wire approximates to a pure gold wire having a purity of no less than 99.99 mass %, so that when the wire diameter is 20 μm or smaller, the mechanical strength will be insufficient for a bonding wire and leaning would be unavoidable. In order to secure stable performance the total amount for the addition should be no less than 0.05 mass % or and more preferably no less than 0.08 mass %. When the total amount of these low content alloy elements is over 2 mass %, the resulting wire would produce a relatively hard melt ball as before and would be liable to cause chip cracking and the junction strength of the compressed ball would be insufficient; thus the total amount of such elements should be 2 mass % or less. In order to secure stable performance, it is more preferable if the total amount is 1.5 mass % or less.

[0020]

The gold (Au) alloy bonding wire of the present invention requires, as minor trace elements to be added to the alloy, (i) calcium (Ca), magnesium (Mg) and lanthanum (La), and optionally requires (ii) beryllium (Be) to be added as a first group dopant, and also optionally requires (iii) at least one of cerium (Ce), yttrium (Y) and europium (Eu) to be added as a second group dopant.

The choice of calcium (Ca), magnesium (Mg) and lanthanum (La) as the indispensable additives is to prevent degradation of the surface quality of the capillary as well as to restrict the occurrence of the segregation in the surface of the melt ball of the bonding wire. The prevention of the capillary surface from degrading is maintained even when the optional first group and second group dopants are added.

As the degradation of the surface quality of the capillary is prevented, it is possible to restrict the rise of the frictional resistance the bonding wire receives as it passes inside the capillary. As a result, it is possible to prevent the bonding wire from suffering neck damages even after hundreds of thousands of times of bonding.

[0021]

In the present invention, the reason for choosing (i) calcium (Ca), magnesium (Mg) and lanthanum (La) as mandatory combination of ingredients is as follows:

Calcium (Ca), magnesium (Mg) and lanthanum (La) have an effect of improving the wedge bonding strength at the second bond. When the wire diameter is 20 μm or smaller, there is a tendency that the bonding strength at the second bond becomes low, and hence addition of this combination is necessary. Especially the addition of magnesium (Mg) greatly increases the bonding strength of the second bond. If the amount of magnesium (Mg) is less than 5 mass ppm, any appreciable increase in the bonding strength at the second bond does not occur. Incidentally, the purity of magnesium (Mg) is preferably no less than 99.9 mass %, and more preferably no less than 99.99 mass %. Even if these three elements are added in combination, they do not segregate in the surface of the binary alloy consisting of gold (Au) and low content alloy element(s) palladium (Pd), platinum (Pt) and copper (Cu). In particular, although calcium (Ca) is an element known to segregate in the surface when added to pure gold (Au), it does not segregate in the surface when the matrix is a binary alloy involving low content alloy element(s) specified by the present invention. Also it has not been identified that the three elements calcium (Ca), magnesium (Mg) and lanthanum (La) interact with each other in a manner such as to affect the segregation in the surface of the binary alloy of the present invention, of which the content of one group element(s) is lean. Therefore, even after hundreds of thousands of times of continuous bonding, the quality of the surface of the capillary does not degrade and likewise the inner wall of the fore front part of the capillary, that is, in the vicinity of the wire exit, does not incur accumulation of segregated substance and its oxide; furthermore, the frictional resistance that the capillary imposes on the wire, compression force that the capillary gives to the ball to be compressed, and the heat energy that is taken away from the compressed ball are rendered constant all the time. Hence, by setting the initial bonding conditions properly they are maintained as they are throughout

the hundreds of thousands of times of bonding, and the compressed balls during the bonding operation do not incur neck damages.

[0022]

Also, of these elements, calcium (Ca) and lanthanum (La) are capable of heightening the mechanical strength of the wire. The reason for this is that these added elements synergically perform to increase the mechanical strength of the surface layer of the ultra thin wire, so that the thinner the wire is, the smaller the effect of the central part of the wire will be on the wire's mechanical strength, with the result that the mechanical strength of the surface layer becomes the mechanical strength of the wire as a whole. The reason why the dosages of calcium (Ca) and lanthanum (La) are required to be no less than 5 mass ppm is that otherwise it is not possible to secure sufficiently high mechanical strength of the extremely thinly drawn wire. Incidentally, the purity of lanthanum (La) is preferably no less than 99.9 mass %, and more preferably no less than 99.99 mass %. The purity of calcium (Ca) is preferably no less than 99 mass %, and more preferably no less than 99.5 mass %.

[0023]

These three elements are helpful in creating a melt ball of high sphericity and a compressed ball of high roundness. In particular, when added to the gold (Au) alloy matrix, these elements in the melt ball do not help degrade the quality of the capillary surface during the compression and do not pile up on the fore front part of the capillary. Also, like in the case of other metallic elements, when calcium (Ca), magnesium (Mg) and lanthanum (La) are added in combination, the resulting gold (Au) alloy wire, as it is bonded by compression, causes accumulation of a substance on the surface of the capillary to some extent. However, these co-additive elements hardly cause surface quality degradation, and thus do not cause accumulation of a segregated substance and its oxide on the fore front part of the capillary even after hundreds of thousands of times of bonding. The reason for setting the respective upper limits of the contents of calcium (Ca), magnesium (Mg) and lanthanum (La) to 50 mass ppm is that over this limit the resulting ultra thin wire drawn to a diameter of 20 μm or smaller would fail produce a spherical melt ball during ball bonding, and thus would fail to produce a circular compressed ball. In order to obtain a melt ball of high sphericity and a compressed ball of high circularity with higher certainty, it is

preferable that the upper limits of the contents of calcium (Ca), magnesium (Mg) and lanthanum (La) are respectively 40 mass ppm and the total amount of them is no greater than 100 mass ppm, and in addition to this, the total amount of the minor trace elements is preferably 100 mass ppm or less. When the total amount of the minor trace elements in the gold (Au) alloy matrix exceeds 100 mass ppm, oxide is liable to form on the surface of the melt ball, so that the junction strength at the first bond can be accidentally lost and the surface quality of the capillary tends to be degraded.

Furthermore, in the cases of magnesium (Mg) and lanthanum (La), when the dosage is greater than 50 mass ppm, the capability of a wire having a diameter of 20 μm or smaller to bond to wedge at the second bond is weakened.

[0024]

In the present invention, the reason why beryllium (Be) is chosen to be the first optional additive element is as follows.

In the presence of the indispensable additive elements, i.e., calcium (Ca), magnesium (Mg) and lanthanum (La), the added beryllium (Be) is effective in preventing the surface quality of the capillary from degrading, as the binary alloy consisting of gold (Au) and low content alloy element(s) palladium (Pd), platinum (Pt) and copper (Cu) is bonded by compression. For this reason, with beryllium (Be) and the indispensable elements coexisting in it, the bonding wire of the additive-lean binary gold alloy can be bonded hundreds of thousands of times without causing the shapes of the first bond and the second bond to degrade, and without occurrences of junction failure and neck damages in the compressed ball at the time of bonding.

[0025]

Also, beryllium (Be), when coexisting with the indispensable additive elements, especially lanthanum (La), can improve the circularity of the compressed ball in a greater degree. Incidentally, the purity of beryllium (Be) can be 99 mass % or higher, and preferably 99.9 mass % or higher. Also, beryllium (Be), when co-existing with the indispensable additive elements, especially calcium (Ca), can heighten, in a greater degree, the mechanical strength of the surface layer of the ultra thin wire which is drawn from the additive-lean binary gold alloy of

the present invention, so that even if the wire is as thin as 20 μm or smaller in diameter, the leaning of the bonded wire is prevented to a greater extent. The reason why the lower limit of beryllium (Be) content is set to 1 mass ppm is that below this limit beryllium (Be) fails to heighten the mechanical strength of the wire surface.

On the other hand, beryllium (Be) increases the hardness of the melt ball. The thinner the ultra thin wire is, the smaller the melt ball becomes, and the chip damage caused in the pad during ball bonding becomes greater. The reason why the upper limit of beryllium (Be) content is set to 20 mass ppm is that beyond this limit when a wire having a diameter of 20 μm or less is used in ball bonding the melt ball gets too hard and is apt to cause chip cracking. Also, beyond that limit, the surface of the fore front part of the capillary are apt to be covered with segregated substance and its oxide. In order to secure a stable effect, the content of beryllium is preferably 15 mass ppm or lower.

[0026]

In the present invention, the reason why cerium (Ce), yttrium (Y) and europium (Eu) are chosen to be second group optional additive elements is as follows.

These rare earth elements, when coexisting with the indispensable additive elements, do not cause degradation of the surface quality of the capillary when the wire of the additive-lean binary gold alloy is bonded by compression. In other words, these rare earth elements are, like lanthanum (La), effective in preventing degradation of the surface quality of the capillary and growth of the accumulation of the segregated substance and its oxide. For this reason, even after hundreds of thousands of times of continuous bonding, the first bond and the second bond do not undergo disfigurement or degradation of the surface quality of the capillary, so that the compressed ball does not retain a neck damage after being bonded. The degradation in the surface quality of the capillary is caused in a lesser extent with cerium (Ce) and yttrium (Y) than with europium (Eu). Incidentally, the purities of cerium (Ce), yttrium (Y) and europium (Eu) are 99.9 mass % or higher, and more preferably 99.99 mass % or higher.

[0027]

Also, these rare earth elements, when coexisting with the indispensable additive elements, especially lanthanum (La), can heighten, in a greater degree, the mechanical strength of the surface layer of the ultra thin wire which is drawn from the additive-lean binary gold alloy of the present invention, so that even if the wire is as thin as 20 μm or smaller in diameter, the leaning of the bonded wire is prevented to a greater extent. In other words, as has been known heretofore, these rare earth elements are helpful in that by increasing the rigidity of the ultra thin wire itself, its loop forming ability is sustained and the circularity of the compressed ball at the first bonding is maintained. These effects are similar to those of beryllium (Be). The reason why the lower limits for these rare earth elements are set to 1 mass ppm is that below this limit, like beryllium (Be), an improvement in mechanical strength is not obtained. Also, the reason why the upper limits for these rare earth elements are set to 20 mass ppm is that beyond this limit, like beryllium (Be), when a wire having a diameter of 20 μm or less is used in ball bonding the melt ball gets too hard and is apt to cause chip cracking.

[0028]

In the present invention, it is possible to opt beryllium (Be) out of the first optional additive elements and at the same time opt any one out of the second group optional additive elements consisting of cerium (Ce), yttrium (Y) and europium (Eu), and add them together to the alloy matrix.

The reason why the lower limit of beryllium (Be) content is set to 1 mass ppm is that below this limit beryllium (Be) fails to heighten the mechanical strength of the wire surface. This combined use of beryllium (Be) and any one of the second group additive elements of the present invention does not give rise to a segregation in the surface of the additive-lean binary alloy. Incidentally, it is thought that the rare earth elements constituting the second group optional additive elements bring about similar effects to the additive-lean binary alloy of the present invention as lanthanum (La) does.

Embodiments of the invention

[0029]

Next, the invention shall be described in detail with reference to examples and comparative examples.

[Examples 1 through 44]

Table 1 shows the composition of each sample used in the examples (Nos. 1 through 44).

Additive-lean binary gold (Au) alloys each composed of a 99.999 mass percent-pure gold (Au) and either one of 99.99 mass percent-pure palladium (Pd) and 99.99 mass percent-pure platinum (Pt) and 99.999 mass percent-pure copper (Cu) were added with minor trace elements in amounts (mass ppm) as shown in Table 1, and the resulting alloys are melted and cast in a vacuum melting furnace.

The cast alloy was continuously drawn into a wire and was subjected to a final thermal treatment when the wire diameter was 15 μm as well as when it was 18 μm whereby the elongation percentage was controlled to 4 %.

[0030]

[Table 1]

Table 1: Chemical composition of gold alloy wires of Examples

Example No.	matrix alloy (mass %)				minor trace elements (mass ppm)						
					indispensable elements			optional elements			
	Au	Pd	Pt	Cu	Ca	Mg	La	Be	Y	Ce	Eu
1	balance	0.10			10	40	10				
2	balance		0.10		20	30	15				
3	balance			0.10	30	20	20				
4	balance	0.25			10	10	15				
5	balance		0.25		10	30	20				
6	balance			0.25	15	35	25				
7	balance	0.50			15	10	40				
8	balance		0.50		25	30	30				
9	balance			0.50	30	15	35				
10	balance	0.75			30	30	35				
11	balance		0.75		40	10	15				
12	balance			0.75	40	35	20				
13	balance	1.00			15	10	10				
14	balance		1.00		25	15	10				
15	balance			1.00	10	10	15	5			
16	balance	1.50			10	30	20	15			
17	balance		1.50		15	35	25	10			
18	balance			1.50	15	10	40		25		
19	balance	0.10	1.00		25	30	30		15		
20	balance	0.25	0.10		30	15	35		10		
21	balance	0.75		0.25	30	20	30			15	
22	balance		0.75	0.75	40	10	14			5	
23	balance	0.10	0.10	0.10	35	15	10			25	
24	balance	0.30	0.30	0.30	30	10	15	5		10	
25	balance	0.10			25	15	10	10	10	10	

26	balance		0.1 0		20	25	20				10
27	balance			0.10	15	10	30		15	10	
28	balance	0.25			20	30	10		15		10
29	balance		0.2 5		25	15	20	5	25		
30	balance			0.25	10	20	25	8	5		15
31	balance	0.50			40	10	15	10		11	
32	balance		0.5 0		30	20	10	5			25
33	balance			0.50	10	10	15	5	5	5	
34	balance	0.75			10	30	20	8		15	5
35	balance		0.7 5		15	30	15	15	5	5	10
36	balance			0.75	15	10	40	5	5	10	5
37	balance	1.00			45	40	40				
38	balance		1.0 0		35	45	40				
39	balance			1.00	30	35	45				
40	balance	1.50			40	30	40	10			20
41	balance		1.5 0		45	35	25		25		
42	balance			1.50	30	30	30	15		10	15
43	balance	0.10	1.0 0		25	40	40	10	5	10	10
44	balance	0.30	0.1 0		45	30	10		10	10	

[0031]

[Comparative Examples Nos. 1 through 5]

The compositions of the additive-lean binary gold (Au) alloys, which were prepared as the comparative samples in the same manner as in the above Examples except that the contents of the minor trace elements were modified differently, are shown in Table 2. These additive-lean binary gold (Au) alloys of the Comparative Examples were spun into an ultra thin wire in the same manner as in the Examples, being subjected to a final thermal treatment when the wire diameter was 15 μm as well as when it was 18 μm whereby the elongation percentage was controlled to 4 %. The resultant wires of the Comparative Examples as well as the Examples were evaluated in the same manner.

[0032]

[Table 2]

Table 2: Chemical composition of gold alloy wires of Comparative Examples

Comparative Example No.	matrix alloy (mass %)				minor trace elements (mass ppm)						
					indispensable elements			optional elements			
	Au	Pd	Pt	Cu	Ca	Mg	La	Be	Y	Ce	Eu
1	balance	0.03									
2	balance	1.00	1.00	1.00							
3	balance	0.50	1.00		3	30	75				
4	balance			1.00	15	20	10	40			
5	balance	0.10			40	10	15		25	80	60

[0033]

These ultra thin wires were each continuously bonded to a 50- μ m square Al pad (film thickness being about 1 μ m) laid on a Si chip by the ball bonding method of the ultrasonic-and-thermoccompression hybrid bonding system in the atmosphere by way of the first bonding, and thereafter the wires were bonded to a lead made of 42Alloy plated with Ag by the wedge bonding method of the ultrasonic-and-thermoccompression hybrid bonding system by way of the second bonding and thus formed a wire connection. In the first bond, all the balls were formed within the face of the 50- μ m square Al pad.

The estimation of the neck strengths of the bonding wires of the Examples and Comparative Examples was conducted in the following manner. The loop span was set to 3 mm and the loop height was set to 200 μ m. The neck strength was determined by changing reverse motion value, a parameter related to the bonding operation. In particular, the reverse motion is an operation of transferring the capillary from the position immediately above the first bond to the central position of the IC chip. The distance of this transfer from the position immediately above the first bond is the definition of the reverse

motion value. On this transferring, the wire bends at its neck. With the other parameters identical, the smaller the reverse motion value is, the smaller the angle of bending becomes; thus the greater the reverse motion value is, the larger the angle of bending becomes, which means that the stress imposed on the neck becomes the greater. The results of the estimation are given in Table 3 and Table 4. In a case wherein there occurred not a neck breakage after 200th bonding with a reverse motion value of 1000 μm , the rating is very good, which is represented in the tables as a duplex circle "◎", in a case wherein there occurred not a neck breakage after 200th bonding of a reverse motion value of 500 μm , the rating is good, which is represented in the tables as a circle "○", and in a case wherein there occurred at least one neck breakage during 200-time bonding of a reverse motion value of 500 μm , the case is given a mark of a triangle "△".

[0034]

With the bonding wires of the Examples and Comparative Examples, the number of junction (bonding) failures that took place during 500,000 times of wire bonding operation using respective wires was observed. In this rating, the loop span was set to 2 mm. The results of the rating is shown in Tables 3 and 4. The number of junction failures is the sum of the number of failures at the first bond and that at the second bond, and if the resulting failure number is zero, the rating of ◎ is given, and if the failure number is no more than 5, a rating represented by ○ is given, and when the failure number is more than 5, a rating represented by △ is given. Incidentally, in a case wherein a junction failure took place at the first bond and then another at the second bond consecutively, or in the opposite order around, and as the result the bonding operation could not be continued, a worst rating of × is given.

[0035]

The junction quality of each bonding wire of the Examples and Comparative Examples was estimated by means of the following pull test.

The pull test employed "4000 Multipurpose Bond tester", a product of DAGE Corporation, whereby a measurement of breaking load was made by lifting with a hook the middle part of the loop span of the bonding sample immediately after the beginning of the continuous bonding. The results of the estimation are

given in Tables 3 and 4.

The estimation of "the quality of a bondage" was rated as follows: an average value of breaking load was taken among 20 wires each of diameters 18 μm and 15 μm with respect to each sample. In the case of a wire diameter of 18 μm , if the average value was 3.5×10 mN or greater, a highest rating represented by $\odot$ is given; similarly, if the average value was in a range of 1.5×10 to 5×10 mN, a rating represented by $\circ$ is given; and if the average value was lower than 1.5×10 mN, a rating represented by Δ is given.

Then, in the case of a wire diameter of 15 μm : if the average value of the breaking load was 2.5×10 mN or greater, the highest rating represented by $\odot$ is given; if the average value was in a range of 1.0×10 to 2.5×10 mN, the rating represented by $\circ$ is given; and if the average value was lower than 1.0×10 mN, the rating represented by Δ is given.

[0036]

Next, the junction quality of each bonding wire of the Examples and Comparative Examples after 500,000 times of wire bonding operation was estimated in the following manner.

With respect to the bonding samples obtained after 500,000 times of wire bonding, the same pull test as conducted on the samples obtained immediately after the bonding operation was conducted. The result of the estimation is shown in Tables 3 and 4.

With regard to 20 pieces each of the wires of 18- μm diameter and 15- μm diameter obtained after 500,000 times of wire bonding, an average pull breaking load value of the pieces was calculated, and it was compared with the pull breaking load value as of immediately after the beginning of the bonding operation, and the lowering in the pull breaking load was observed: if the lowering was less than 20 %, the rating represented by $\odot$ is given; if it was 20 - 50 %, the rating represented by $\circ$ is given; and if it was greater than 50 %, the rating represented by Δ is given. In the case wherein the number of the wire bonding operation did not reach 500,000 times so that the estimation could not be done, the case was given the rating represented by $\times$.

[0037]

The quality of the surface of the fore front part of the capillary after participating in 500,000 times of wire bonding operation with respect to each of bonding wires of the Examples and Comparative Examples was estimated by analyzing for elements at 2000-time intensification and by mapping using an "Electron Probe Microanalyzer EPMA-1600" a product of Shimadzu Corporation. The minor trace elements were concentrated by the mapping result, and the elements covering the underneath portion of the capillary entered in Table 3 and Table 4.

[0038]

[Table 3]

Table 3: Results of estimation of gold alloy wires of Examples

Example No.	Results of wire estimation				elements detected on capillary surface
	neck strength	quality of 500,000 times wire bonding	initial pull test	pull test after bonding	
1	◎	○	○	○	none
2	◎	◎	◎	◎	none
3	◎	◎	◎	◎	none
4	◎	◎	◎	◎	none
5	◎	◎	◎	◎	none
6	◎	◎	◎	◎	none
7	◎	○	○	○	none
8	◎	○	◎	◎	none
9	◎	◎	◎	◎	none
10	◎	○	◎	○	none
11	◎	○	○	○	none
12	◎	○	○	○	none
13	◎	◎	◎	◎	none
14	◎	◎	◎	◎	none
15	◎	◎	◎	◎	none
16	◎	○	○	○	none
17	◎	○	◎	◎	none
18	◎	○	○	○	none
19	◎	○	◎	○	none

20	◎	○	◎	○	none
21	◎	○	◎	○	none
22	◎	○	○	○	none
23	◎	○	◎	◎	none
24	◎	◎	◎	◎	none
25	◎	◎	◎	◎	none
26	○	◎	◎	◎	none
27	◎	◎	◎	◎	none
28	○	○	◎	◎	none
29	◎	○	◎	○	none
30	○	◎	◎	◎	none
31	◎	○	○	○	none
32	○	○	◎	○	none
33	◎	◎	◎	◎	none
34	○	○	◎	◎	none
35	○	○	○	○	none
36	○	○	○	○	none
37	◎	○	○	○	none
38	◎	○	○	○	none
39	◎	○	○	○	none
40	○	○	○	○	none
41	◎	○	○	○	none
42	○	○	○	○	none
43	○	○	○	○	none
44	○	○	○	○	none

[0039]

[Table 4]

Table 4: Results of estimation of gold alloy wires

Comparative Example No.	Results of wire estimation				elements detected on capillary surface
	neck strength	quality of 500,000 times wire bonding	initial pull test	pull test after bonding	
1	Δ	○	Δ	Δ	none
2	○	Δ	○	Δ	none
3	Δ	×	Δ	×	La
4	Δ	×	Δ	×	Be
5	Δ	×	Δ	×	Ce Eu

[0040]

As is clear from the Examples described above, the gold (Au) alloy bonding wire of the present invention is capable of allowing continuous bonding if the added amounts of the minor trace elements are within the specified ranges even if the wire diameter is as small as 18 μm or smaller.

In contrast to this, in the Comparative Examples, desirous results were not obtained for the reasons postulated as below.

In Comparative Example 1, the content of palladium (Pd), an indispensable element, was short of the amount prescribed by the present invention.

In Comparative Example 2, the total content of palladium (Pd), platinum (Pt) and copper (Cu), at least one of which is indispensable, exceeded the amount prescribed by the present invention.

In Comparative Example 3, the content of calcium (Ca), which is an indispensable minor trace element, was short of the amount prescribed by the present invention, and also the content of Lanthanum (La), another indispensable minor trace element, exceeded the prescribed amount.

In Comparative Example 4, the content of beryllium (Be), which is an optional minor trace element of the present invention, exceeded the prescribed amount.

In Comparative Example 5, the total content of cerium (Ce) and europium (Eu), which are optional minor trace elements of the present invention, exceeded the prescribed amount.

In Comparative Examples 3 - 5, it was observed that these minor trace elements contained in excess stuck in the form of a substance created by surface segregation or in the form of their oxides on the surface of the capillary.

The Industrial Applicability

[0041]

The alloy of the present invention is useful for making a bonding wire used in semiconductor devices, especially ones for automotive vehicles and ones employed in high temperature environments.

What is claimed is:

1. A gold alloy bonding wire drawn to a diameter of 20 μm or less, which is made from a gold alloy matrix and minor trace elements,
said gold alloy matrix comprising at least one out of palladium, platinum and copper, which have a purity of no less than 99.9 mass %, in a total amount of 0.05 to 2 mass % and gold of a purity of no less than 99.999 mass %,
characterized in that said minor trace elements consist of calcium in an amount of 5 - 50 mass ppm, magnesium in an amount of 5 - 50 mass ppm, and lanthanum in an amount of 5 - 50 mass ppm.
2. A gold alloy bonding wire drawn to a diameter of 20 μm or less, which is made from a gold alloy matrix and minor trace elements,
said gold alloy matrix comprising at least one out of palladium, platinum and copper, which have a purity of no less than 99.9 mass %, in a total amount of 0.05 to 2 mass % and gold of a purity of no less than 99.999 mass %,
characterized in that said minor trace elements consist of calcium in an amount of 5 - 50 mass ppm, magnesium in an amount of 5 - 50 mass ppm, lanthanum in an amount of 5 - 50 mass ppm, and beryllium in an amount of 1 - 20 mass ppm.
3. A gold alloy bonding wire drawn to a diameter of 20 μm or less, which is made from a gold alloy matrix and minor trace elements,
said gold alloy matrix comprising at least one out of palladium, platinum and copper, which have a purity of no less than 99.9 mass %, in a total amount of 0.05 to 2 mass % and gold of a purity of no less than 99.999 mass %,
characterized in that said minor trace elements consist of calcium in an amount of 5 - 50 mass ppm, magnesium in an amount of 5 - 50 mass ppm, lanthanum in an amount of 5 - 50 mass ppm, and also at least one of cerium, yttrium and europium in a total amount of 1 - 30 mass ppm.
4. A gold alloy bonding wire drawn to a diameter of 20 μm or less, which is made from a gold alloy matrix and minor trace elements,
said gold alloy matrix comprising at least one out of palladium, platinum and copper, which have a purity of no less than 99.9 mass %, in a total amount of 0.05 to 2 mass % and gold of a purity of no less than 99.999 mass %,
characterized in that said minor trace elements consist of calcium in an

amount of 5 - 50 mass ppm, magnesium in an amount of 5 - 50 mass ppm, lanthanum in an amount of 5 - 50 mass ppm, beryllium in an amount of 1 - 20 mass ppm, and also at least one of cerium, yttrium and europium in a total amount of 1 - 30 mass ppm.

5. A gold alloy bonding wire as claimed in any one of claims 1 through 4, characterized in that a total amount of all minor trace elements is 100 mass ppm or smaller.